Magnetic Three-dimensional Pose Control System for Micro Robots in the Human Head

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Abstract: Micro robots are devices that have the ability to revolutionize the area of medicine. These devices work without cables, move easily in aqueous environments, and have the ability to be controlled in different ways, allowing them to access very small places. Currently, three-dimensional electromagnetic actuating systems have been proposed for the movement of micro robots by means of arrangements of Helmholtz and Maxwell coils with various functionalities but with high energy consumption. The present investigation proposes a system of coils of Helmholtz and Maxwell with analysis of the currents used to move the micro robot, complementing with the simulation of movement of the micro robot in the subarachnoid region of the human brain by means of Unity. In this way, it is planned to take a first step to know the design of a real system so that in the future, microrobots can reach difficult areas such as the subarachnoid region.

1 INTRODUCTION

Minimally invasive surgery is one of the greatest advances that technology has made in recent years. In recent years there has been an enormous growth in the area of medical robotics, mainly through the growing demand for good quality medical care in the countries of great development, reinforced by the creation of a new social network. High quality means, among other things, prevention rather than care, precision and repeatability of the least possible intrusion in the patient's body (Dario et al., 2000).

Micro robots are planned to be used in various surgical procedures, taking advantage of the relative large size of some human organs. However, with the reduction of dimension to less than one millimeter, many additional places in the human body will be available for these interventions. The micro robots could navigate the natural pathways of the human body, which would allow intervention with minimal trauma. Although the idea of performing a surgical intervention entirely by a robot seems futuristic, the handling of micro robots using fiber optic cables or radio links, while the surgeon observes and directs the progress (Flynn et al., 1998) is increasingly more real, it could be said that micro robot operations are an increasingly real possibility (Joseph et al., 2005).

One of the most innovative features of microrobots today, is that they can be moved in liquid environments, and for this numerous methods have been proposed, among which are mechanical swimming structures that replicate the wave movement by means of links, designs similar to fish that use actuators GMA (Magneto strictive Alloy), SMA (memory alloy actuators), PZT (piezoelectric actuators), among others. Recent studies have shown that the micro robots with the best results would be mostly biomimetic and many of them would use magnetic fields to feed and wirelessly control the micro robot (Abbott et al., 2009). These micro robots could be could be effective depending on the environment in which the micro robot is located. A lot of micro robots are being inspired so that in the future they imitate the movements of nature and also use techniques that facilitate the management of the power of the system and the wireless control. The micro robots, have the ability to enhance the treatment of cancer in the central nervous system (Nelson et al., (2010). The use of neuronal prostheses and deep brain stimulation are other promising

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applications for wirelessly guided micro robots, since they can even remain as implants. Nowadays, the possibility of using micro robots in medical procedures such as the precise transport of drugs within the body, brachytherapy, transport of stem cells in order to rebuild damaged tissues, transport of electrodes in the brain and treatments such as hyperthermia and thermoablation (Nelson et al., 2010).

Currently, there is a large amount of research in the human brain and to a large extent in the subarachnoid area, which is located in the skull, made with radiology techniques and myelography methods (Thijssen et al., 1979), more specifically, measuring the distance between the dura mater and the spinal cord to his left, right, anterior and posterior (Kosa et al., 2007). A case of great interest is the treatment of brain tumours, which are extremely lethal and therefore, it becomes imperative to intervene by means of surgeries that are mostly of great complexity. Despite many efforts, the administration of drugs to the brain remains a challenge, mainly because the brain barrier, consisting of endothelial cells that are closely interconnected and that cover the entire interior of the walls of the brain vessel, are mostly insurmountable for the therapeutic molecules that seek to leave the medication in the affected area, which means that leaving the medicine is sometimes impossible. In fact, 98 % of new drugs used in the central nervous system to fight brain cancer and other chronic diseases cannot enter the brain following a systemic administration (Pardridge, 2003).

In this particular case, the area of interest is the nervous system, more specifically the subarachnoid region. The central nervous system is made up of the brain, the spine, and the cerebrospinal fluid in which the brain and spine are bathed. This fluid is colourless and has properties similar to water (relative viscosity between 1.020-1.027poise, density 1.0032-1.0048kg m-3, has a pH of 7.35-7.7, in addition to a surface tension 60-63 * 10-6 N mm -1) (Murphy et al., 2016). The space of the subarachnoid region tends to be symmetrical on the left and right sides of the spinal cord, while the anterior and posterior segments are highly asymmetrical and it is difficult to access both in practice, extending from vertebra L2 to the second segment of the sacrum (Moore and Dalley, 2009). A 2.5 mm micro robot could navigate in the lateral or posterior section of the subarachnoid space in approximately half of the world population, while a 1.5 mm micro robot would reach 85 % of the same population (Duffner et al., 2003). To access the brain, procedures such as craniotomies are used, however, cerebrospinal fluid samples are usually taken with a lumbar puncture between the L3 and L4 vertebrae (third and fourth lumbar vertebra). Therefore, it is possible to insert a micro

robot in this area and navigate to the brain to intervene the target, leaving the skull intact, this being one of the biggest advances recently put to test by means of catheter (Purdy et al., 2005). In the present project, the Maxwell and Helmholtz coils will be used to magnetize the micro robot and move it by a simulation of the human subarachnoid region, more specifically, a pair of Maxwell coils and two pairs of stationary Helmholtz coils.

The use of these coils was initially proposed by Yesin et al (Yesin et al., 2006), specifying that a pair of Helmholtz coils and a pair of Maxwell are organized in a certain direction, making the static performance constant, in order to direct and drive the micro robots. This work is organized as follows: Section 2 will briefly discuss the advances that have existed in the study of the Helmholtz and Maxwell coils, section 3 will give a brief description of the main mathematics governing the Helmholtz and Maxwell coils, later in section 4 we will talk about the base equations that were used and in the subsection that is here we will talk about the proposed equations whose emphasis is to determine the current that the coils would need for the proposal, then in section 5 will talk about the anthropometry of the human head, which was used to design the system in Unity3D, later the results of this research will be shown in section 6 and finally the conclusions of the project are dictated together with the future works that this would have.

2 MAGNETIC NAVIGATION

Magnetic navigation systems are defined as a set of software and hardware used in a certain region of the human body. Generally, these include a magnet that has a front field which extends far enough to project a magnetic field into the operating region in the patient (Creighton and Burgett, 2006). In other cases, two magnets are used, a support for them and a positioner that selectively changes the location of the magnets (Werp and Creighton, 2010). On the other hand, (Choi et al., 2009) proposed a special magnetic navigation system to obtain a static system. In this, there are two pairs of Helmholtz and Maxwell coils that generate a uniform magnetic flux in a desired direction in a xy plane. Subsequently, there was an improvement in the magnetism obtained by the propulsion system with only one pair of Maxwell coils, which is more advantageous for smaller volumes, obtaining a lower power consumption (Choi et al., 2009). Similarly, (Ha et al., 2010) proposed a magnetic propulsion consisting of three Helmholtz coils and one Maxwell coil.

Understanding the fields required for the wireless control of permanent magnets is relatively simple, since the magnetization of the material can be modelled as a constant. The use of analytical models for higher precision magnetic forces, allows the current existence of symmetric bodies axially smooth and with magnetic qualities. Another relevant advance was the obtaining of a flat movement of a ferromagnetic micro robot, using a pair of Helmholtz and Maxwell coils, which are rotated by means of a motor (Yu et al., 2010). This rotation generates a magnetic pair, which rotates the micro robot, while the Maxwell coils generate a propulsion force, allowing the microbot to move in the X and Y (Zhang et al., 2009) planes. However, the propulsive force produced by the rotation is very small and cannot overcome the force of the blood flow. Arai et al. proposed an electromagnetic actuation system consisting of three pairs of Helmholtz coils and showing the results in a spiral-type micro robot (Sendoh et al., 2004). Previous studies proposed an electromagnetic action system, using two pairs of stationary coils to produce the locomotion of a ferromagnetic micro robot in the form of a cylinder in a 2D (Choi et al., 2009) plane.

Apart from the aforementioned systems, another was proposed consisting of a pair of Helmholtz and Maxwell stationary coils and a pair of rotational ones, the Helmholtz and Maxwell helices were formulated in the central x axis (Jeong et al., 2010). As a last innovation, there is a 3D locomotion system for an electromagnetic actuation system, consisting of three pairs of Helmholtz coils that magnetize and align the micro robot and two pairs of Maxwell coils that drive it. In addition, the three pairs of Helmholtz coils generate a rotational magnetic field and rotate the micro robot (Yu et al., 2010). The currents necessary for the operation of magnetic navigation systems are an important factor to take into account when studying electromagnetic propulsion systems For the previously described case (3D locomotion system) it is stated that for the generation of uniform magnetic fields in the three pairs of Helmholtz and Maxwell coils, the number of turns of the winding is fundamental, since when increasing or decreasing the winding, the magnetic field will increase or decrease respectively. In this way, controlling the magnetic field becomes relatively easy (Yu et al., 2010). In the case of a microrobot of approximately 2.5 cm x 6.4 mm x 3.2 mm built with 12 piezoelectric micromotors, a current of 2.7 x 10-5 A was needed for its operation, which was calculated providing a torque of 4.6 x 1 0- 5 Nm per second (Westebring-van der Putten et al., 2008). When dealing with small dimensions, technological problems must be taken into account, for example, that currently there are no sufficiently small motors and cables. In practice, solenoids less than 1 mm3 are hardly feasible; In addition, the maximum current density is limited by the dissipation of energy, that is, the dissipation is related to the size of the microbot (Elwenspoek and Wiegerink, 2012).

The consumption of energy in these propulsion systems is a present problem in most of the current proposals in this field. Taking as an example the magnetic propulsion system OctoMag, able to create gradients of field of up to 2 T and fields of orientation of up to 50 mT, while driving the robot (Kummer et al., 2010). The creation of these fields involves considerable energy needs, which in turn result in much greater heat dissipation, affecting the performance of the system in long periods of use. Thinking about this problem, the research is currently focused on developing magnetic navigation systems that reduce the energy requirements, which in turn are able to achieve sufficient control over the microbot. One of them consists of “pulling” of a microbot by means of magnetic field gradients. This method of propulsion involves the reduction of the amplitude of the currents that flow in the Maxwell coils, which are used continuously during the operation and their resistances are usually higher than those of the Helmholtz coils. Therefore, a decrease in the currents flowing in the Maxwell coils has a dramatic impact on the power consumption of the general platform (Jeong et al., 2010).

3 DESCRIPTION OF THE COILS

3.1 Helmholtz Coils

Helmholtz coils consist of two coaxial wire loops that are usually mounted on a common axis at a fixed distance. In essence, by passing a certain amount of equal currents through them, a highly uniform magnetic field is generated within a limited space on the centroid between the coils. Thus, Helmholtz coils are ideal for use in the magnetic fields of a device when it is tested, and in this way produce precise and repeatable results (Webb et al., 2007). The magnetic navigation of a micro robot consists of the generation of a force F and a torque T that are expressed by the equation 1. Within a magnetic field, any type of object with magnetic qualities will develop a torque and force. The torque obtained is proportional to the intensity of the magnetic field and provides direction to the object, which allows it to align with the generated magnetic field. The magnetic force is directly proportional to the gradient of the magnetic field, and allows the movement of the object to a certain place. The calculation of the magnetic pair, which aligns the microrobot magnet to the applied field is determined by the following equation

$$\vec{F} = V.(\vec{M}.\nabla)\vec{B} \quad (1)$$

$$\vec{T} = V\vec{M} \times \vec{B} \quad (2)$$

Where do you have:

- $\vec{F}$: vector of the general strength of the robot.
- V: volume of the robot.
- $\vec{M}$: robot magnetization vector.
- $\triangledown$: magnetization gradient.
- T: torque needed by the micro robot.
- $\vec{B}$: magnetic field vector.

You can express the equation 2 in a more intuitive and useful way:

$$\vec{T} = V\left[Mx(\vec{\imath}) + My(\vec{\jmath}) + Mz(\vec{k})\right] \times [Bx(\vec{\imath}) + By(\vec{\jmath}) + Bz(\vec{k})] \quad (3)$$

Where Mx, My and Mz denote the magnetization value of each axis (Cao et al. (2012)).

3.2 Maxwell Coils

The Maxwell coils consist of two coils side by side that generate a certain amount of current which goes in opposite directions to drive the objects determined by the user. They are used to a large extent when working on magnetic propulsion projects, since they generate constant magnetic gradients to produce uniform propulsion forces at the center of the coil (Cao et al., 2012). The magnetic flux density and its gradient, associated with the arrangement of Helmholtz and Maxwell coils along the main axis, can be approximated to a constant value. Therefore, said quantities will depend directly on the current applied to the system, by the following equations:

$$B = \frac{8}{5\sqrt{5}} \frac{\mu0\, NH}{RH} \vec{I} = k * IH \quad (4)$$

$$\nabla * B = \frac{48\sqrt{3}}{49\sqrt{7}} \frac{\mu0 * NM}{RM^2} \vec{I} = g * IM \quad (5)$$

Where:

- NH: number of laps of the pair of Helmholtz coils.
- RH: radius of the Helmholtz coil pair.
- IH: current obtained in the pair of Helmholtz coils.
- k: constant value.
- $\triangledown$: magnetization gradient. • B: magnetic field.
- μ0: constant value.
- NM: number of turns of the Maxwell coil pair.
- RM: radius of the Maxwell coil pair.
- $\vec{I}$: current vector obtained.
- IM: current obtained in the pair.

Where k and g are proportional coefficients, which depend on the radius of the coils and the number of turns for Helmholtz and Maxwell respectively. In order to simplify the model, it is assumed that the robot is a solid disk, immersed in a liquid with a small Reynolds number (the Reynolds number is a dimensionless quantity that has the same value in any coherent system of units and allows to determine if a fluid is laminar or turbulent), perpendicular to its axis. With that consideration, the drag force in a closed space can be approximated by:

$$\overrightarrow{FD} = \frac{4\pi\mu d v}{log\frac{2d0}{r} - \frac{1}{4}\frac{r}{d0}^{2}} \quad (6)$$

Where

•$\overrightarrow{FD}$: drag force vector.
• μd: dynamic viscosity of the fluid.
• v: speed handled by the micro robot.
• r: robot radio.
• d0: distance from the center of the micro robot to the space where it is confined
• h: thickness of the micro robot.

On the plane, the forces present are summarized below:

$$\overrightarrow{Fmag} + \overrightarrow{FD} = m\vec{a} \quad (7)$$

Where:

- Fmag: magnetization force.
- $\overrightarrow{FD}$: drag force vector.
- m: mass of the micro robot.
- $\vec{a}$: acceleration of the microrobot in the XYZ plane.

4 PROPOSED MATHEMATICAL MODEL

For this project, the system is considered as a black box as shown below in the Figure 1.

Where:

- θ y φ: position angle of the micro robot with respect to the Maxwell and Helmholtz coils.
- M: magnetization of the micro robot.
- F: force with which the micro robot moves.
- BM, BHx, BHy, BHz: parameters of the Maxwell and Helmholtz coils as the number of laps they carry

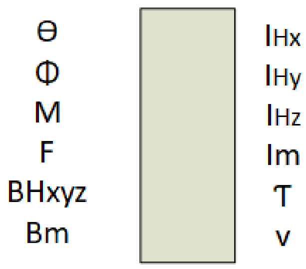

Figure 1: Output input system for Maxwell and Helmholtz coils.

and the radius of these.

- IHx: current of the Helmholtz coils on their x axis.
- IHy: current of the Helmholtz coils on their y axis.
- IHz: current of the Helmholtz coils on their z axis.
- IM: current of the Maxwell coils.
- τ: torque needed by the micro robot.
- V: speed that the micro robot carries when moving.

The arrangement of the coils to be used is the one proposed by (Choi et al., 2013), is represented in Figure 2. In this we can see a Helmholtz type configuration that is located along an axis, separated by a distance dh that is equal to its radius rh. There is also a pair of Maxwell coils whose separation in their electromagnets, dm is $\sqrt{}$ 3rm, being rm the radius of the coils, with the flow of the currents in opposite directions.

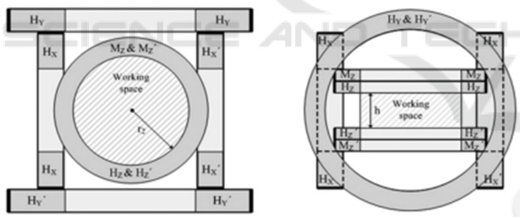

Figure 2: Representation in blocks of the proposed system, taken from (Choi et al., 2013).

The magnetic field produced by a pair of Helmholtz coils of the x axis can be determined by the law of Biot-Savart, this is supported by (Jeon et al., 2010) and is described below:

$$HHX = \left[k.\frac{ix.nx}{rx}, 0{,}0\right]^T \tag{8}$$

$$HHY = \left[0, k.\frac{iy.ny}{ry}, 0\right]^T \tag{9}$$

$$HHZ = \left[0{,}0, k.\frac{iz.nz}{rz}\right]^T \tag{10}$$

The following is the value of the constant k, (Jeon et al., 2010):

$$k = \left(\frac{4}{5}\right)^{\frac{3}{2}} \tag{11}$$

It is known that the total magnetic field is compounded by the sum of the partial magnetic fields, that is, those related to the axes x, y and z. It is obtained that:

$$HH = HHX + HHY + HHZ \tag{12}$$

From where it can be calculated that:

$$\overrightarrow{HH} = k\left[\frac{ix.nx}{rx}, \frac{iy.ny}{ry}, \frac{iz.nz}{rz}\right]^T \left[\frac{A}{M}\right] \tag{13}$$

4.1 Calculation of Modified Maxwell and Helmholtz Currents

In Figure 3 can see the proposed Cartesian plane in which angles will be used for the mathematics of the project.

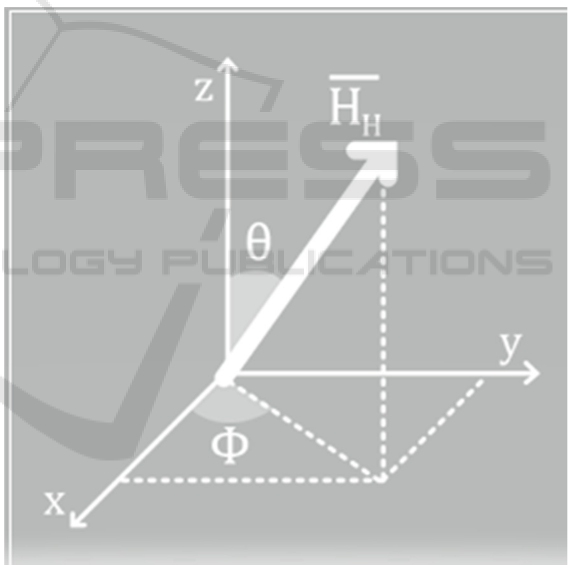

Figure 3: Proposed Cartesian plane.

Taking into account the equations 3, 14, 15 and 16 are obtained:

$$x = HH\ sin\theta\ cos\theta \tag{14}$$

$$y = HH\ sin\theta\ cos\emptyset \tag{15}$$

$$z = HH\ cos\theta \tag{16}$$

Calculating in this way the equation 17 that ends up being the magnetic field generated by the Helmholtz coils.

$$\vec{H} = \begin{bmatrix} sen\theta . cos\theta \\ sen\theta . sen\emptyset \\ cos\theta \end{bmatrix} HH \tag{17}$$

It proceed to equal HH, which is founding the equations 13 and 17, it is then expressed in a vectorial way and the equations of x, y and z are separated, then the following is obtained:

$$k \begin{bmatrix} \frac{ix.nx}{rx} \\ \frac{iy.ny}{ry} \\ \frac{iz.nz}{rz} \end{bmatrix} = \begin{bmatrix} sen\theta . cos\theta \\ sen\theta . sen\emptyset \\ cos\theta \end{bmatrix} HH \tag{18}$$

Reorganizing get that:

$$k\frac{ix.nx}{rx} = HH\ sen\theta cos\emptyset \tag{19}$$

$$k\frac{iy.ny}{ry} = HH\ sen\theta sen\emptyset \tag{20}$$

$$k\frac{iz.nz}{rz} = cos\theta \tag{21}$$

Taking into account all the mathematics raised above, the currents for the Helmholtz coils will be calculated. It is important to remember that this is a fundamental part of a research, since those currents would be the same as the real system could come to use. The equations 22, 23 and 24 will be those that show the currents that will be needed in the three pairs of Helmholtz coils:

$$ix = \frac{HH\ rx}{knx} sen\theta\ cos\emptyset \tag{22}$$

$$iy = \frac{HH\ ry}{kny} sen\theta\ sen\emptyset \tag{23}$$

$$iz = \frac{HH\ rz}{knz} cos\theta \tag{24}$$

Now, it proceed to calculate the torque generated by the Helmholtz coils, which is represented in the following equation:

$$\vec{T} = V[M\ \times B] \tag{25}$$

$$\vec{T} = V\ \mu 0\ [M\ \times H] \tag{26}$$

$$\left|\vec{T}\right| = V.\mu 0\ .|M|.|HH|.sen\delta \tag{27}$$

Where, V is the volume of the micro robot, μ0 is the permeability of the medium and M is the magnetization constant. Next, the mathematics used for the Maxwell coils used in the system will be explained. First, the magnetic field generated by the Maxwell coils is calculated as follows:

$$Hm = \left[-\frac{1}{2}gmx, -\frac{1}{2}gmy, gmz\right] \tag{28}$$

Where gm is a constant that contains the following equation:

$$gm = k\frac{nm.Im}{rm^2} \tag{29}$$

From where it can be seen that:

$$k = \frac{16}{3}\left(\frac{3}{7}\right)^{\frac{5}{2}} \tag{30}$$

By operating the previously described, it is obtained that:

$$\overrightarrow{Hm} = \frac{knm\ Im}{2(rm)^2}\ [-x, -y, 2z] \tag{31}$$

It proceed to calculate the gradient of the Maxwell field and it obtain that:

$$\nabla Hm = \frac{knm\ Im}{2rm}\ [-1, -1, 2] \tag{32}$$

The rule is applied, to obtain the magnitude of ▽ Hm and it can be seen:

$$|\nabla Hm| = \frac{knm\ Im}{2rm^2}\sqrt{1+1+4} \tag{33}$$

$$|\nabla Hm| = \frac{nm\ Im}{rm^2}\ K \tag{34}$$

Where K is:

$$K = \frac{16}{3}\left(\frac{3}{7}\right)^{\frac{5}{2}}\left(\frac{3}{2}\right)^{\frac{1}{2}} \tag{35}$$

Now, it is necessary to calculate the force with which the micro robot goes to a place:

$$\vec{F} = \mu V\left(\vec{M}.\nabla\vec{H}\right) \tag{36}$$

$$\overrightarrow{|F|} = \left|\mu V\left(\vec{M}.\nabla\vec{H}\right)\right| \tag{37}$$

$$F = \mu V\left|\vec{M}.\nabla H\right| \tag{38}$$

$$F = \mu V.|M|.|\nabla H| \tag{39}$$

Now, the equation 34 replaces the equation 39 and it get:

$$F = \mu V|M|\frac{nmImK}{rm^2} \tag{40}$$

Finally it proceed to clear Im, to obtain the current of the Maxwell coils:

$$Im = \frac{F\ rm^2}{\mu V|M|nmK} \tag{41}$$

With this, the calculation of the current that would be used by the Helmholtz and Maxwell coils is terminated.

5 ANTHROPOMETRY OF THE HUMAN HEAD

Most of the dimensions of the human body, like natural phenomena and other events in nature, are distributed normally, that is, according to the Gaussian distribution (Avila et al., 2007). Many continuous random variables have a density function whose graph is bell-shaped, as seen in 4. Normally, in a mostly homogeneous population, the distribution of any of its anthropometric dimensions is normal and, therefore, estimates, calculations and, in general, any statistical procedure, can be carried out according to the properties of this distribution, which is very convenient given the ease that the treatment of this distribution supposes.

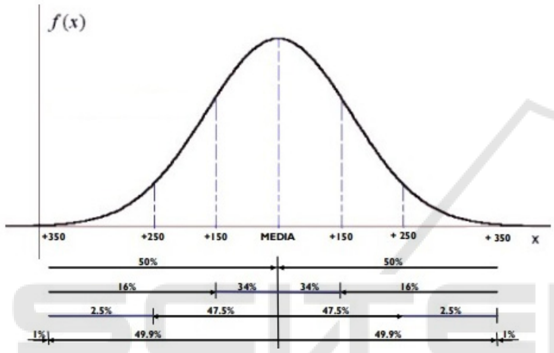

Figure 4: Example of normal distribution curve.

To carry out the simulation system, the anthropometry analysed by (Avila et al., 2007) from which the case study was taken of people between 18 and 65 years old, where the anthropometry of workers was analysed. From this study we obtain the table 1:

Table 1: Anthropometry table of the human head.

Length (mm)	Width (mm)	Height (mm)
150	176	281

Considering the table 1 the measurements of a three-dimensional model of a human head using the Blender software were rearranged. Once this modified head was obtained, a cavity was made in it simulating the arachnoid space (which is where the micro robot will move) and placing the human brain in the middle of said space. A complete platform was simulated in the Unity video game engine, where the user can see moving the micro robot at will and also see the current that it would need in the Helmholtz and Maxwell coils. Unity3D is a development engine for the creation of games and interactive 3D content, it is fully integrated and offers many features to facilitate the development of video games. It is available as a development platform for Microsoft Windows, OS X, Linux. The purpose of this experiment is give direction a micro robot according to magnetic field's direction, to later implement a force and analyse how much current could be needed and all this in a simulation of the arachnoid area of the human head. It is a fact that the arachnoid area is a very small region of the brain and it would be important to have an object that can be controlled and moved artificially by means of the mathematics previously described, this in order to expand the medical barriers, and that future, there are many functionalities that can be achieved in bioengineering.

6 RESULTS

Once the scene in Unity was developed, a series of tests were carried out in which it was sought to analyze the necessary current of the Helmholtz and Maxwell coils to move the micro robot depending on the angles θ y φ, which are changed by the user as the application is running.

The parameters shown in Table 2 refer to the characteristics of the microbot and the coils that are needed for the development of this project and that can be changed by the user as he or she wants to change the focus of the investigation. For this, the user must first know the area of the human body that he wants to analyze and the measures that characterize it, since the data that is entered into the software must be exact.

Table 2: Table of environment parameters and proposed micro robot.

Strength magnetic field	0.01 Newton 3183 A / m
N laps Hx	340
N spins Hy	110
N turns Hz	340
Radio Hx	0.09 m
Radio Hy	0.09 m
Radio Hz	0.085 m
N spins M	6000
Radio M	0.145 m
Mag Mr	0.145 m
Radio Mr	500 µ m

Where:
- Hx: Helmholtz coil in x.
- Hy: Helmholtz coil in y.
- Hz: Helmholtz coil in z.

• M: Maxwell coil.
• Mr: micro robot.
• Mag: magnetization.

In the proposed interface in Figure 5 the arrangement of coils to be used is shown, the yellow coils are the Helmholtz coils and the blue coils are the Maxwell coils. On the left side, there is a small panel that, when pressed, returns the values that will be of interest to the user, such as current, speed, and angles.

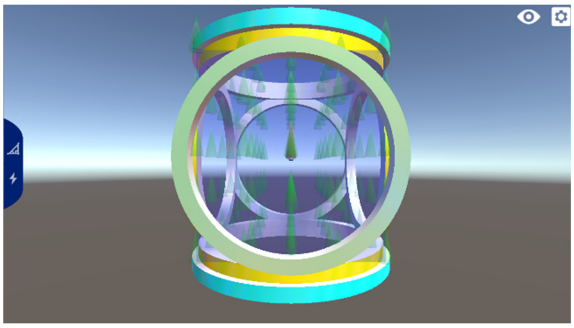

Figure 5: Initial scene.

Initially it can be seen magnetic field lines in Figure 6 without aligning, the user must then indicate with the keys of his computer where he wants them to be aligned, and the micro robot will rotate to that position; the micro robot is represented by a small point (whose size the user can modify) and the direction in which it goes is characterized by a red vector, being the green ones, the vectors of the generated magnetic field. Subsequently, a force must be applied in the micro robot (the magnitude of this is variable and it is advisable to specify it before moving the micro robot) that will take it to a position of the working area that can be in the "x" axis, and "y"axis or "z" axis.

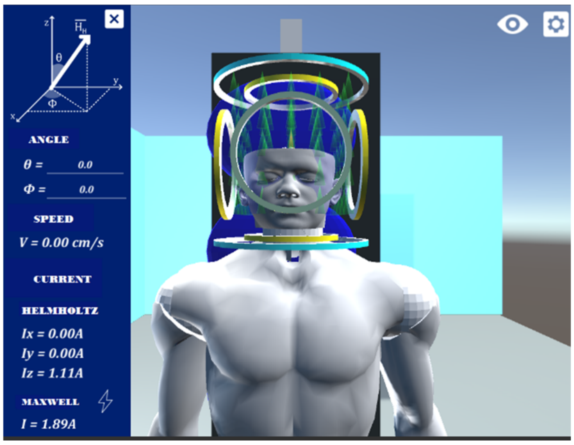

Figure 6: Unfolded scene.

Figure 7 shows the interior of the proposed human head, which, as mentioned above, has at its center the brain and a space between it and the walls that represent the arachnoid section. At this point, only current on the "z" axis is evident since the magnetic field lines are only directed on this axis.

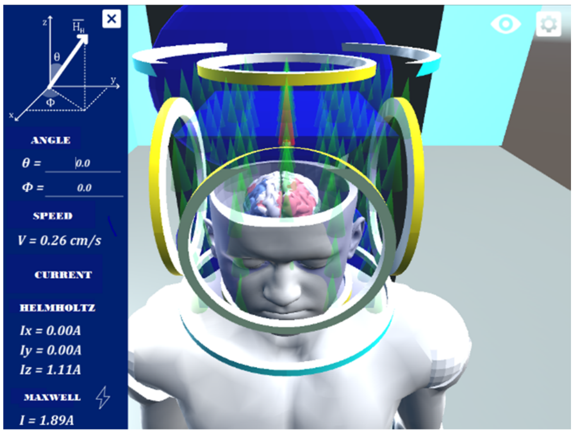

Figure 7: View of the brain inside the skull.

Once the user has handled the software, the results returned by the user will be analysed through Matlab. Matlab is a mathematical software tool that offers an integrated development environment (IDE) with a programming language of its own (M language), allows the analysis of results to subsequently graph them, in this way it can see in a three-dimensional image the results that are obtained. Below is the graph that shows how the current in the Helmholtz coils behaves on its axis "x", "y" and "z".

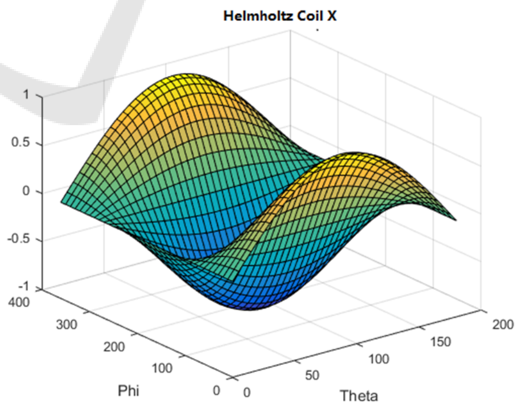

Figure 8: Current obtained in the Helmholtz coils, x axis.

The peak of the currents in the Helmholtz coils corresponding to the x axis and shown in Figure 8 is reached when the angles θ and φ reach the values of 0◦ and 360◦ respectively. This means that when the microrobot reaches these angles, it will need the largest number of current, this explanation applies in the same

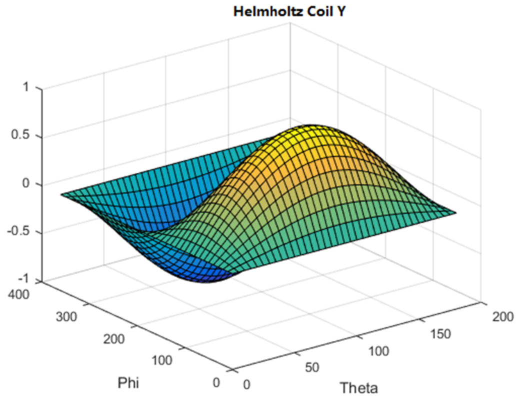

Figure 9: Current obtained in the Helmholtz coils, axis y.

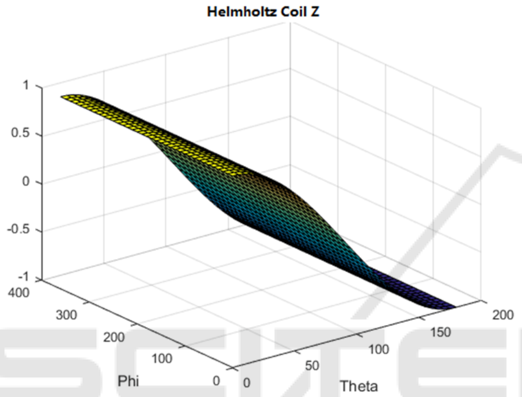

Figure 10: Current obtained in the Helmholtz coils, z-axis.

way for the other coil arrangements explained here. In Figure 9 it is seen how the peaks of the currents are reached when the angles θ and φ reach 90◦ in both cases. In Figure 10 the peak of the currents is reached when θ and φ are in values of 0◦ and 360◦ respectively. The currents obtained for the proposed working area and for the characteristics of the micro robot are the following:

Table 3: Currents obtained.

Hx	1.1A
Hy	1.1A
Hz	1.1A
M	1.8A

The currents obtained in this system are not large compared to those recorded by other studies where they also use sets of coils, for example the one made by (Jeon et al. (2010)) where currents of 100A, 85.1A and 68.8A are reached, although keeping the proportions, because the aforementioned coil arrangement is not similar to the one proposed in this study. It is important to clarify that these flows are equivalent to those necessary according to the data that the user previously entered in the proposed software and that correspond to a specific working area; also, it is difficult to make a comparison with respect to the amount of current that the system might need, since there is not much information about a magnetic navigation study of a microrobot in the arachnoid area of the human brain or using the proposed current array in this studio.

7 CONCLUSIONS

This article showed the implementation of a simulated magnetic navigation system that aligns a micro robot to the lines of the magnetic field created as desired by the user, a force is applied and subsequently the device moves to a certain position in the work area, which is the arachnoid area of the human head. The system consists of an arrangement of three Helmholtz coils and a pair of stationary Maxwell coils, a human body modelled in Blender whose head has the aforementioned real measurements; also has a panel located on the left side of the screen where the angles that the micro robot has in real time, the speed it takes (to ensure that it handles a speed appropriate for a job in real life) and the current in the three coils of Helmholtz and the Maxwell coil. For this purpose, equations were used so that the tool designed in Unity development engine would show the results and move the micro robot. The micro robot moves in a simulated area such as the arachnoid area human head at the users will according to the requirements that the user placed at the beginning of the simulation. The tool proves that by having technological means it could have a micro robot that can easily navigate in this area of human head to be able to download other types of treatments, and this way be able to fight different types of diseases and thus, expand the borders of biomedicine.

Further works will concern the implementation of this system in a physical model, to compare the results obtained in the simulation and the real ones, also proposes the idea of testing the algorithm in another work scenario taking into account that the requirements of the coils change according to the working area.

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